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Signed, this 15st day of December, 2008

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[DOCUMENT TITLE] SPECIFICATION
[TITLE OF INVENTION] FUEL CELL SYSTEM
[SCOPE OF CLAIM FOR PATENT]
[Claim 1]

A fuel cell system comprising:

a fuel cell stack for generating power by electrochemical reaction between a fuel gas and an oxidant gas; and

a catalytic combustor for combusting a mixed gas between the fuel gas or an anode off-gas discharged from an anode of the fuel cell stack and the oxidant gas or a cathode off-gas discharged from a cathode of the fuel cell stack, wherein control means is operative such that at least during the ignition period until the catalytic combustor is discriminated to be sufficiently activated from commencement of supplying the mixed gas to the catalytic combustor, a fuel gas concentration of the mixed gas is maintained in a given range whereas after the ignition period has been elapsed, the mixed gas is available to be supplied to the catalytic combustor even if the fuel gas concentration lying at a value deviated from the given range.

[Claim 2]

The fuel cell system according to claim 2, wherein the control means is operative such that an average concentration of the fuel gas in the mixed gas during the ignition period is

within a given range.

[Claim 3]

The fuel cell system according to claim 2, wherein the control means is operative such that the fuel gas is continuously supplied during the ignition period.

[Claim 4]

The fuel cell system according to claim 2, wherein the control means is operative such that air is continuously increased during the ignition period.

[Claim 5]

The fuel cell system according to claim 2, wherein the control means is operative such that the fuel gas is transiently increasingly supplied during the ignition period.

[Claim 6]

The fuel cell system according to claim 2, wherein the control means is operative such that an air increase amount is transiently increasingly adjusted during the ignition period.

[Claim 7]

The fuel cell system according to any of claims 2 to 6, wherein the control means is operative such that a maximum concentration of the fuel gas in the mixed gas during the ignition period is within the given range.

[Claim 8]

The fuel cell system according to any of claims 1 to 7,

wherein the given range is set such that a combustion temperature of the mixed gas is more than an active temperature of the catalytic combustor.

[Claim 9]

The fuel cell system according to any of claims 1 to 7, wherein the given range is set such that a combustion temperature of the mixed gas is less than a concentration which is a combustible limit of the fuel gas.

[Claim 10]

The fuel cell system according to any of claims 1 to 7, wherein the given range is set such that a combustion temperature of the mixed gas is more than an active temperature of the catalytic combustor and less than the concentration which is the combustible limit of the fuel gas.

[0001]

[TECHNICAL FIELD OF THE INVENTION]

The present invention relates to a fuel cell system and in particular to a fuel cell system which improves a combustion characteristic of an anode off-gas.

[0002]

[CONVENTIONAL ART]

A fuel cell system to electrochemicallly react fuel gas, such as hydrogen gas, and oxidant gas containing oxygen to one another to allow an electric energy to be taken out from

electrodes disposed on both sides of an electrolyte membrane. Especially, a solid polymer fuel cell employing a solid electrolyte attracts public attention as an electric power supply for an electric vehicle because of a low operating temperature and ease of handling. That is, a fuel cell powered vehicle is an ultimate clean vehicle on which a hydrogen absorbing device, such as a high pressure hydrogen tank, a liquid hydrogen tank and a hydrogen absorbing amorphous allow tank, is installed to allow hydrogen, supplied from the same, and air including oxygen to be delivered to the fuel cell to accomplish reaction for taking out the electric energy from the fuel cell to drive a motor connected to drive wheels with only water remaining as emission matter.

[0003]

In the solid polymer fuel cell , when using air as oxidant gas, nitrogen passing from a cathode to an anode through the electrolyte membrane remains in an anode system to lower a hydrogen partial pressure, resulting in deterioration in an efficiency of the fuel cell. For this reason, if the nitrogen remains in the anode system to some extent, there is a need for fuel gas containing nitrogen to be purged to the outside of the system from a purge valve located at an outlet of the anode. Such operation is sometimes referred to as "anode-purging". When this takes place, the gas discharged from the anode is

called as anode off-gas that includes flammable gas containing hydrogen. It is undesirable for hydrogen to be directly discharged to the outside and, hence, the purged anode off-gas is combusted in a catalytic combustor, thereby enabling mixed gas containing nitrogen and steam to be exhausted to the outside of the system.

[0004]

Among technologies for combusting anode of—gas, a typical one technology is known from Patent Document 1. This technology takes the form of a structure that comprises a mixture which permits a portion of cathode off-gas and anode off-gas to be mixed in a fuel cell, a regulator unit that regulates the flow rate of combustion exhaust gas in an exhaust gas delivery line, depending on the flow rate of feed gas in a fuel line, based upon a predetermined relationship such that a mixture ratio in the mixer between anode off-gas and cathode off-gas lying at a value deviated from an explosion limit.

[0005]

[Patent Document 1]

JP7-78626A (Page 1 in Fig. 1)

[0006]

[PROBLEM TO BE SOLVED BY THE INVENTION]

However, since the related art technology takes the form of the structure wherein anode off-gas and cathode off-gas are

combusted at the mixture ratio lying at a value deviated from the explosion limit, in case of combusting mixed gas with the mixture ratio falling at a value less than an explosion lean-limit, the flow rates of oxidant gas needed for combustion increase and, therefore, the amount of catalyst needed for processing fuel gas is increased. This results in an issue wherein the catalytic combustor is required to be formed in an excessively large size or a recovery efficiency of heat energy is deteriorated due to the combustion temperature being relatively dropped to a lower level.

[0007]

Further, another issue encountered in the related art resides in that when the mixture ratio lies at a value greater than an excessively high concentration limit, the flammable gas is discharged to the outside of the system, causing a deteriorated reliability in a safety.

[0008]

[MEANS FOR THE SOLUTION OF THE PROBLEM]

The present invention is made in view of the foregoing problem and is provided with a fuel cell system comprising a fuel cell stack for generating power by electrochemical reaction between a fuel gas and an oxidant gas, a catalytic combustor for combusting a mixed gas between the fuel gas or an anode off-gas discharged from an anode of the fuel cell stack and the oxidant gas or a cathode off-gas discharged from a

cathode of the fuel cell stack, wherein control means is operative such that at least during the ignition period until the catalytic combustor is discriminated to be sufficiently activated from commencement of supplying the mixed gas to the catalytic combustor, a fuel gas concentration of the mixed gas is maintained in a given range whereas after the ignition period has been elapsed, the mixed gas is available to be supplied to the catalytic combustor even if the fuel gas concentration lying at a value deviated from the given range.

[0009]

[EFFECT OF THE INVENTION]

According to the present invention, at least during the ignition period until the catalytic combustor is discriminated to be sufficiently activated from commencement of supplying the mixed gas to the catalytic combustor, a fuel gas concentration of the mixed gas is maintained in a given range whereas after the ignition period has been elapsed, the mixed gas is available to be supplied to the catalytic combustor even if the fuel gas concentration lying at a value deviated from the given range. Therefore, since an operation can be performed at an appropriate condition in accordance with a sate of the catalytic combustor, a collection efficiency of the thermal energy can be enhanced while avoiding an increase in size of the catalytic combustor.

[0010]

Further, because of no discharge of the combustible gas outside of the system, safety and reliability can be improved.

[0011]

[EMBODIMENTS]

[First embodiment]

Referring now to FIG. 1 and FIG. 3, a first embodiment of a fuel cell system according to the present invention is described in detail. FIG. 1 is a structural view of the fuel cell system of the first embodiment.

In FIG. 1, the fuel cell system of the presently filed embodiment is shown including a hydrogen supply unit (fuel gas supply unit) 1 that supplies hydrogen as fuel gas to an anode 4 of a fuel cell stack 3 through an anode gas supply conduit 11, and an air supply unit (oxidant gas supply unit) 2 that supplies air as oxidant gas to a cathode 5 through a cathode gas supply conduit 14. The fuel cell stack 3 is supplied with hydrogen and air to achieve electrochemical reaction for thereby generating electric power.

[0012]

When this takes place, anode off-gas, that is not consumed in the anode 4, is expelled from the anode 4, and cathode off-gas resulting from a portion of oxidant gas consumed in the cathode 5 and containing moisture created through electric power generation is expelled from the cathode 5.

[0013]

During normal operation of the fuel cell stack 3, a whole

amount of anode off-gas is delivered through an anode off-gas recirculation conduit 12 to an anode gas supply conduit 11 and then introduced to the anode 4 again. On the other hand, cathode off-gas is delivered through a cathode off-gas delivery conduit 15 and the humidifier 10, that humidify hydrogen and air to be introduced to the fuel cell stack 3, to the catalytic combustor 7 through which cathode off-gas is exhausted to the outside.

[0014]

The catalytic combustor 7 is comprised of a mixer 23 in which hydrogen or anode off-gas and air or cathode off-gas are mixed to form uniformly mixed gas, and a combustion chamber 24 that carries a combustion catalyst to combust mixed gas to form combustion gas. The combustion gas is heat exchanged with coolant in the coolant heat exchanger 8 and then exhausted to the outside of the system through an exhaust pipe 19.

[0015]

For the purpose of maintaining the fuel cell stack 3 at an optimum operating temperature suitable for electric power generation, the fuel cell stack 3 is internally formed with coolant passages which are not shown. During a normal operation mode, coolant flows from a coolant outlet port of the fuel cell stack 3 to pass through a coolant passage regulator valve 22, the coolant cooling unit 9, the coolant pump 21, and a coolant passage inside a drain tank 25, and is circulated through a

coolant inlet port of the fuel cell stack 3, the coolant passage inside the fuel cell stack 3 and the coolant outlet port thereof. And, reaction heat developed in the fuel cell stack 3 is radiated to the outside from the coolant cooling unit 9 and thus, the fuel cell stack 3 is maintained at a prescribed appropriate temperature.

[0016]

Also during a start-up mode of the fuel cell system, since the temperature of coolant remains at a low level, hydrogen and air are introduced to the catalytic combustor 7 to combust these components, and the combustion heat is used for heating coolant passing through the coolant heat exchanger 8 raise the coolant temperature so as to warm up the fuel cell stack 3 to an optimum operating temperature.

[0017]

Connected to a system controller (serving as a control means) 34 that controls the fuel cell system are a temperature detector 32 that detects the temperature of the catalytic combustor 7, a voltage detector 33 that detects an output voltage of the fuel cell stack 3, a pressure detector 26 that detects the pressure of anode off-gas at an anode outlet, and a temperature detector 27 that detects the temperature of anode off-gas at the anode outlet.

[0018]

The system controller 34 is applied with detection signals from these detectors and discriminates an activated condition of the catalytic combustor 7 and controls the hydrogen supply unit 1, the air supply unit 2, an anode off-gas discharge valve 35 serving as a control valve, a cathode off-gas discharge valve 36, serving as a cathode pressure control valve, for thereby controlling a fuel concentration of mixed gas between hydrogen or anode off-gas and air or cathode off-gas in the catalytic combustor 7.

[0019]

FIG. 2 is a timing chart for illustrating how the system controller 34 forming part of the first embodiment controls a hydrogen concentration of mixed gas to be supplied to the catalytic combustor 7, with FIG. 2(a) representing the concentration of hydrogen supplied to the catalytic combustor, FIG. 2(b) the temperature of the catalytic combustor 7 and FIG. 2(c) the concentration of exhaust hydrogen discharged from the catalytic combustor 7.

[0020]

First, at a time t1, when the temperature of the catalytic combustor 7 remains sufficiently lower than the catalyst activating temperature, the system controller 34 is responsive to the detection signal delivered from the temperature detector 32 and operates the anode off-gas discharge valve 35 and the

air supply unit and the cathode off-gas discharge valve 36 to commence supply of the mixed gas between hydrogen or anode off-gas and air or cathode off-gas to the catalytic combustor 7 at a given hydrogen concentration greater than a catalyst activating lower limit and less than a flammable lean-limit.

[0021]

Since the catalytic combustor 7 has almost no activity when supplied with the mixed gas at the given hydrogen concentration greater than the catalyst activating lower limit and less than the flammable lean-limit, in an initial stage, exhaust gas is expelled at a hydrogen concentration closer to that of hydrogen supplied to the catalytic combustor 7. However, since the activation of the catalyst is facilitated during an ignition period between t1 and t2 and a conversion efficiency is improved, the concentration of exhaust hydrogen drops and the temperature of the catalytic combustor 7 rises.

[0022]

And, at a time t2, when the temperature of the catalytic combustor 7 has reached the catalyst activating temperature, the system controller 34 increases the flow rate of hydrogen to be supplied by the hydrogen supply unit 1 to increase the hydrogen concentration to a value greater than the flammable lean-limit. Although this allows the hydrogen concentration to rise, since the temperature of the catalytic combustor 7 has

already reached the catalyst activating temperature, hydrogen in mixed gas introduced to the catalytic combustor 7 is sufficiently converted such that the concentration of exhaust hydrogen nearly zeroes and is maintained at a hydrogen concentration extremely lower than that of the flammable lean-limit.

[0023]

Next, referring to a control flow chart of FIG. 3, description is made of control to be performed by the system controller 34 forming part of the presently filed embodiment.

[0024]

Initially, in step S10, the system controller 34 discriminates to find whether the fuel cell stack 3 remains in a given status. Here, discrimination is made to find whether the detected voltage level resulting from the voltage detector 33, by which the output voltage of the fuel cell stack 3 is detected, is below a given voltage level. If the detected voltage level is found to exceed the given voltage level, operation is routed back to step S10.

[0025]

In contrast, if the detected voltage level is found to remain lower than the given voltage level, operation is routed to step S12 to permit the system controller 34 to generate a discharge signal requesting purge operation. Upon receipt of

this discharge signal, the anode off-gas discharge valve 35 is opened by the system controller 34 to allow anode off-gas to be supplied from the anode off-gas recirculation unit 6 to the catalytic combustor 7 at a given flow rate while controlling the fuel supply unit 1 to allow hydrogen to be supplied to the fuel cell stack 3 at a flow rate increased by a value substantially equal to the flow rate of anode off-gas to be discharged from the anode off-gas recirculation unit 6 and permitting hydrogen to be kept under a fixed pressure level. In this respect, for the sake of simplifying a structure, the anode off-gas discharge valve 35 exemplarily takes the form of a shut-off valve.

[0026]

In next step S14, the flow rate of anode off-gas to be discharged from the fuel cell stack 3 is estimated based on the pressure and the temperature of anode off-gas detected by the pressure detector 26 and the temperature detector 27, respectively.

[0027]

In subsequent step S16, depending upon the estimated flow rate of anode off-gas, calculation is made to obtain a demanded incremental flow rate of air

 (i. e. , a demanded flow rate of cathode off-gas) required for maintaining mixed gas to be supplied to the catalytic combustor 7 at a hydrogen

concentration greater than a value causing the combustion temperature to raise to the activating temperature of the catalytic combustor 7 and less than the flammable lean-limit (of a value below 4 %: here, for instance, 3 %) of hydrogen.

[0028]

In succeeding step S18, depending upon the incremental flow rate of air obtained through calculation, the system controller 34 controls the air supply unit 2 to increase the flow rate of air to be supplied to the fuel cell stack 3 and, thereafter, anode off-gas is discharged through the anode off-gas discharge valve 35.

[0029]

Here, during the ignition period (between t1 and t2 in FIG. 2) where the catalytic combustor 7 is discriminated to be sufficiently activated after commencing to discharge anode off-gas, the temperature of the catalytic combustor 7 remains relatively low and the conversion efficiency remains inadequate, resulting in a probability where a portion of anode off-gas is discharged to the outside of the system in unburned status. When this takes place, since the unburned hydrogen remains at a concentration below the flammable lean-limit, no ignition occurs inside or outside the system, resulting in no fear of occurrence of deterioration in a safety of the system.

[0030]

In consecutive step S20, discrimination is made to find whether the temperature of the catalytic combustor 7 detected by the temperature detector 32 exceeds the activating temperature. If the temperature of the catalytic combustor 7 is found to be lower than the activating temperature, operation is waited in step S20.

[0031]

At a time where the temperature of the catalytic combustor 7 is found to exceed the activating temperature, since the catalytic combustor 7 has a sufficiently facilitated activity with a resultant extremely less probability in occurrence of unburned hydrogen being exhausted, operation is routed to step S22 to interrupt operation for increasing the air flow rate while allowing discharge of anode off-gas to be continued.

[0032]

In subsequent step S24, operation is waited until the detected voltage level of the voltage detector 33 for detecting the output voltage of the fuel cell stack 3 reaches a value greater than a given voltage value. If the detected voltage level is found to exceed the given voltage value, operation is routed to step S26 wherein the anode off-gas discharge valve 35 is closed to interrupt the discharging of anode off-gas whereupon operation is restored to a given operating condition.

[0033]

According to the first embodiment set forth above, due to an ability of the system controller performing control such that at least during the ignition period wherein the catalytic combustor 7 is found to be adequately activated after commencing to supply mixed gas, the fuel gas concentration in mixed gas is maintained in a given range and after the catalytic combustor 7 is found to be adequately activated, even the mixed gas lying at a value deviated from a range of the above-described fuel gas concentration is available to be supplied, it is possible to operate the fuel cell system under an appropriate condition depending upon the condition of the catalytic combustor 7.

[0034]

Further, by selecting a fuel gas concentration range during the ignition period to be greater than the concentration at which the combustion temperature of mixed gas reaches the activating temperature of the catalytic combustor, the catalyst of the catalytic combustor can be rapidly activated, reducing emission of unburned gas.

[0035]

In addition, by selecting the fuel gas concentration range during the ignition period to be less than the concentration that lies at a flammable limit of fuel gas, exhaust gas can be safely exhausted to the outside of the system without causing exhaust gas from being ignited even in a case

where inadequate combustion takes place in the catalytic combustor with a resultant unburned fuel gas being discharged.

[0036]

Also, under a condition, such as in cold temperatures, where the catalytic combustor 7 is hard to be activated, a control concept of the present invention can be applied to a case where ignition is carried out using an auxiliary heater means such as an electric heater.

[0037]

(Second Embodiment)

Next, referring to FIG. 4 and FIG. 5, description is made of a fuel cell system of a second embodiment of the present invention. The fuel cell system of the second embodiment is similar in structure to that shown in FIG. 1, with like component parts bearing the same reference numerals for a simplicity of description.

[0038]

The fuel cell system of the presently filed embodiment differs from that of the first embodiment in that during the ignition period, no incremental operation for the air flow rate is performed and the system controller (control means) 34 controls in a way to intermittently supply anode off-gas at given time intervals shorter than the ignition time period.

[0039]

FIG. 4 is a timing chart for illustrating how the system controller 34 forming part of the second embodiment controls a hydrogen concentration of mixed gas to be supplied to the catalytic combustor 7, with FIG. 4(a) representing the concentration of hydrogen supplied to the catalytic combustor 7, FIG. 4(b) the temperature of the catalytic combustor 7 and FIG. 4(c) the concentration of exhaust hydrogen discharged from the catalytic combustor 7.

[0040]

First, at a time t1, when the temperature of the catalytic combustor remains sufficiently lower than the catalyst activating temperature, the system controller 34 is responsive to the detection signal produced by the temperature detector 32 and controls the hydrogen supply unit 1 and the air supply unit 2 to allow the catalytic combustor 7 to be intermittently supplied with hydrogen or anode off-gas and continuously supplied with air or cathode off-gas, respectively. When this takes place, an average hydrogen concentration of mixed gas between hydrogen or anode off-gas to be intermittently supplied and air or cathode off-gas to be continuously supplied is set to be higher than a catalyst activation lower limit and lower than the flammable lean-limit.

[0041]

When the supply of mixed gas at such an average

concentration has been commenced, since the catalytic combustor 7 has almost no activity, exhaust gas with the hydrogen concentration closer to the concentration of supplied hydrogen is expelled in an initial stage. However, since the catalyst activation is facilitated during the ignition period between t1 and t2 to improve the conversion efficiency, the exhaust hydrogen concentration intermittently drops and the temperature of the catalytic combustor rises in upwardly protruded stages with round configurations.

[0042]

And, at a time t2, when the temperature of the catalytic combustor 7 has reached the catalyst activating temperature, the system controller 34 controls the hydrogen supply unit 1 to allow anode off-gas to be supplied to the catalytic combustor 7 to cause the mixed gas to lie at the hydrogen concentration greater than the flammable lean-limit. Although this allows the concentration of supplied hydrogen to raise, since the temperature of the catalytic combustor 7 has reached the catalyst activating temperature, hydrogen in mixed gas is sufficiently converted such that the concentration of exhaust hydrogen nearly zeroes and is maintained at a low concentration extremely lower than that of the flammable lean-limit.

[0043]

This allows the average hydrogen concentration during the

ignition period to remain at the concentration that induces the combustion temperature above the activating temperature of the catalytic combustor 7 and at the concentration (of a value less than 4 %: here, for instance, 3 %) below the flammable lean-limit of hydrogen.

[0044]

For this reason, the hydrogen concentration in mixed gas can be regulated in a high response due to the presence of a short distance between the anode off-gas discharge valve 35 and the catalytic combustor 7 while making it possible to use the anode off-gas discharge valve 35 comprised of a simplified structure such as a shut-off valve. Also, since no increase in the flow rate of air results in, it is possible to restrict the load of a compressor forming the air supply unit 2 from increasing, resulting in a capability of suppressing an increase in electric power consumption.

[0045]

Next, referring to a control flow chart of FIG. 5, description is made of control to be performed by the system controller 34 forming part of the presently filed embodiment.

[0046]

Initially, in step S30, the system controller 34 discriminates to find whether the fuel cell stack 3 remains in a given status. Here, discrimination is made to find whether

the detected voltage level resulting from the voltage detector 33, by which the output voltage of the fuel cell stack 3 is detected, is below a given voltage level. If the detected voltage level is found to exceed the given voltage level, operation is routed back to step S30.

[0047]

In contrast, if the detected voltage level is found to remain to be lower than the given voltage level, operation is routed to step S32 to permit the system controller 34 to generate an discharge signal requesting purge operation. Upon receipt of this discharge signal, the system controller 34 intermittently opens and closes the anode off-gas discharge valve 35 to allow the anode off-gas recirculation unit 6 to discharge anode off-gas to the catalytic combustor 7 at a given flow rate and, at the same time, the hydrogen supply unit 1 is controlled to increase the flow rate of hydrogen by an amount substantially equal to the flow rate of anode off-gas being discharged from the anode off-gas recirculation unit 6 while permitting the pressure of hydrogen to be kept at a fixed level. In this respect, for the sake of simplifying a structure, the anode off-gas discharge valve 35 takes the form of a shut-off valve.

[0048]

In next step S34, the flow rate of anode off-gas is

estimated based on the pressure and the temperature of anode off-gas detected by the pressure detector 26 and the temperature detector 27, respectively.

[0049]

In subsequent step S36, depending upon the estimated flow rate of anode off-gas, calculation is made to find out an intermittent discharge condition of anode off-gas required for maintaining the hydrogen concentration in mixed gas to be supplied to the catalytic combustor 7 at a concentration greater than the combustion temperature above the activating temperature of the catalytic combustor 7 and at a concentration (of a value below 4 %: here, for instance, 3 %) less than the flammable lean-limit of hydrogen.

[0050]

In succeeding step S38, depending upon the intermittent discharge condition of anode off-gas resulting from calculation, the system controller 34 operates to allow the anode off-gas discharged valve 35 to be intermittently opened or closed to intermittently discharge anode off-gas. When this takes place, since a discharge flow rate of cathode off-gas is maintained at a level before the discharge signal has been outputted, no change occurs in the discharge flow rate of cathode off-gas and no probability occurs in an increase in electric power consumption of the air supply unit 2.

[0051]

Here, during the ignition period (between t1 and t2 in FIG. 4) in which discrimination is made to find out that the catalytic combustor 7 has been sufficiently activated after start of discharging anode off-gas, the temperature of the catalytic combustor 7 remains relatively low and the conversion efficiency remains inadequate, resulting in a probability where a portion of anode off-gas is discharged in unburned status. When this takes place, since unburned hydrogen remains at a concentration that exceeds the flammable lean-limit for an extremely short period of time, no ignition occurs inside or outside the system, resulting in no fear of occurrence of deterioration in a safety of the system.

[0052]

In consecutive step S40, discrimination is made to find whether the temperature of the catalytic combustor 7 detected by the temperature detector 32 exceeds the activating temperature. If the temperature of the catalytic combustor 7 is found to be less than the activating temperature, operation is waited in step S40.

[0053]

At a time where the temperature of the catalytic combustor 7 is found to exceed the activating temperature, since the catalytic combustor 7 has a sufficiently facilitated activity

with a resultant extremely less probability in occurrence of unburned hydrogen being discharged, operation is routed to step S42 where the anode off-gas discharge valve 35 begins to continuously discharge anode off-gas.

[0054]

In subsequent step S44, operation is waited until the detected voltage level of the voltage detector 33 for detecting the output voltage of the fuel cell stack 3 reaches a value greater than the given voltage value. If the detected voltage level is found to exceed the given voltage value, operation is routed to step S46 wherein the anode off-gas discharge valve 35 is closed to interrupt the discharging of anode off-gas whereupon operation is restored to a given operating condition.

[0055]

According to the second embodiment set forth above, due to the presence of control through which the average concentration of fuel gas in mixed gas falls in a given range, a ratio between a total amount of unburned fuel gas and a total amount of exhaust gas to be discharged during the ignition period can be regulated to fall in a given range, thereby enabling a safety to be enhanced even when exhaust gas is expelled to a dead air space.

[0056]

Further, by performing control so as to intermittently

supply fuel gas, mixed gas can be supplied in pulsed phases at a fuel gas concentration greater than a given range to increase a heat value due to supply of hydrogen at a high concentration for thereby improving a temperature rise characteristic of the catalytic combustor, and due to the presence of control through which the unburned hydrogen concentration in exhaust gas remains in the average level below the flammable limit during the ignition period, it is possible to perform warm-up of the catalytic combustor and the discharging of exhaust gas in a safe manner.

[0057]

Also, on the contrary, attempt may be undertaken to allow anode off-gas to remain at the given flow rate and to permit the flow rate of air to intermittently increase such that the average hydrogen concentration during the ignition period lies at a concentration in which the combustion temperature exceeds the activating temperature of the catalytic combustor 7 and at a concentration below the flammable lean-limit of hydrogen.

[0058]

In such case, the heat value can be increased and thus, the activation of the catalytic combustor 7 can be relatively and rapidly performed.

[0059]

Also, in an alternative, it is so controlled that the

maximum concentration of fuel gas in mixed gas during the ignition period falls in a given range. In this case, the exhaust gas can be safely expelled to the outside of the system with no occurrence of exhaust gas being ignited at all times during the ignition period wherein a probability exists for unburned fuel gas to be discharged.

[0060]

(Third Embodiment)

Next, referring to FIG. 6 and FIG. 7, description is made of a fuel cell system of a third embodiment of the present invention. The fuel cell system of the third embodiment is similar in structure to that shown in FIG. 1.

[0061]

The fuel cell system of the presently filed embodiment differs from that of the first embodiment in that the flow rate of anode off-gas is increased based on a hydrogen concentration incremental pattern, that is preliminarily obtained for the ignition period, so as to allow the hydrogen concentration in mixed gas to transiently vary from the lower concentration than the flammable lean-limit to the higher concentration than the flammable lean-limit and to allow the average hydrogen concentration during the ignition period to fall in a value above the concentration at which the combustion temperature reaches a value greater than the activating temperature of the

catalytic combustor 7 and at the hydrogen concentration (of 4 %: here, for instance, 3 %) less than the flammable lean-limit of hydrogen.

[0062]

The presently filed embodiment contemplates to take a structure in which the anode off-gas discharged valve 35 is comprised of a flow regulator valve and control is performed such that the flow rate of anode off-gas increases in dependence on the temperature rise of the catalytic combustor 7 and under a condition where the temperature remains low and the activity of the catalyst remains low, the flow rate of anode-off gas to be supplied remains low and the flow rate of unburned hydrogen decreases whereupon the flow rate of anode off-gas increases as the temperature increases for thereby suppressing deterioration in a safety and reliability of the system.

[0063]

However, when this takes place, in case where the temperature of the catalytic combustor 7 does not increase even after an elapse of a given pattern prescribed time interval such as a case with the catalyst being deteriorated, the system controller 34 achieves the same control as that of the first embodiment, after an incremental pattern has been terminated for enabling the catalytic combustor 7 to have the activity.

[0064]

FIG. 6 is a timing chart for illustrating how a system controller 34 forming part of the presently filed embodiment controls the mixed gas concentration, with Fig. 6A representing the concentration of hydrogen supplied to the catalytic combustor, Fig. 6B the temperature of the catalytic combustor and Fig. 6C the concentration of exhaust hydrogen discharged from the catalytic combustor.

[0065]

First, at a time t1, when the temperature of the catalytic combustor 7 remains sufficiently lower than the catalyst activating temperature, the system controller 34 is responsive to the detection signal delivered from the temperature detector 32 and opens the anode off-gas discharge valve 35 to commence supply of the mixed gas between hydrogen or anode off-gas and air or cathode off-gas to the catalytic combustor 7. Thereafter, depending upon a selected hydrogen concentration incremental pattern, the system controller 34 increases the opening degree of the anode off-gas discharge valve 35 so as to increase the flow rate of anode off-gas to be supplied to the catalytic combustor 7 to increase the hydrogen concentration in mixed gas in the catalytic combustor 7.

[0066]

When the supply of mixed gas at the hydrogen concentration greater than the catalyst activating lower limit and less than

the flammable lean-limit has been commenced, since the catalytic combustor 7 has almost no activity, exhaust gas with the hydrogen concentration closer to that of supplied hydrogen is expelled in an initial stage. However, since the catalyst activation is facilitated during the ignition period between t1 and t2 to improve the conversion efficiency, the concentration of exhaust hydrogen to be exhausted drops and the temperature of the catalytic combustor rises.

[0067]

And, at a time t2, when the temperature of the catalytic combustor 7 has reached the catalyst activating temperature at t2, the system controller 34 increases the opening degree of the anode off-gas discharge valve 35 so as to increase the flow rate of anode off-gas to be supplied to the catalytic combustor 7 to increase the hydrogen concentration in mixed gas to be supplied to the catalytic combustor 7 to a value greater than the flammable lean-limit. Although this allows the hydrogen concentration to rise, since the temperature of the catalytic combustor 7 has reached the catalyst activating temperature, hydrogen in mixed gas is sufficiently converted such that the concentration of exhaust hydrogen nearly zeroes and is maintained at a low concentration extremely lower than that of the flammable lean-limit.

[0068]

Next, referring to a control flow chart of FIG. 7, description is made of control to be performed by the system controller forming part of the presently filed embodiment.

[0069]

Initially, in step S50, the system controller 34 discriminates to find whether the fuel cell stack 3 remains in a given status. Here, discrimination is made to find whether the detected voltage level resulting from the voltage detector 33, by which the output voltage of the fuel cell stack 3 is detected, is below a given voltage level. If the detected voltage level is found to exceed the given voltage level, operation is routed back to step S50.

[0070]

In contrast, if the detected voltage level is found to remain to be lower than the given voltage level, operation is routed to step S52 to permit the system controller 34 to generate an discharge signal requesting purge operation. Upon receipt of this discharge signal, the system controller 34 opens the anode off-gas discharge valve 35 to allow the anode off-gas recirculation unit 6 to discharge anode off-gas to the catalytic combustor 7 at a given flow rate and, at the same time, the hydrogen supply unit 1 is controlled to increase the flow rate of hydrogen by an amount substantially equal to the flow rate of anode off-gas being discharged from the fuel cell stack 3

while permitting the pressure of hydrogen to be kept at a fixed level.

[0071]

In next step S54, the flow rate of anode off-gas is estimated based on the pressure and the temperature of anode off-gas detected by the pressure detector 26 and the temperature detector 27, respectively.

[0072]

In subsequent step S56, depending upon the estimated flow rate of anode off-gas, the system controller 34 selects an anode off-gas supply pattern to sequentially increase the flow rate of anode off-gas to be supplied to the catalytic combustor 7. In this respect, a plurality of anode off-gas supply patterns, that enable the catalyst to be activated within the shortest time interval for each segment of the flow rates of anode off-gas, are experimentally derived and these patterns are preliminarily stored in the system controller 34.

[0073]

Further, these anode off-gas supply patterns include patterns in which the hydrogen concentration in mixed gas to be supplied to the catalytic combustor 7 lies at a concentration at which the combustion temperature exceeds the activating temperature of the catalytic combustor 7 and a concentration (of 4 %: here, for instance, 3 %) less than the flammable

lean-limit of hydrogen.

[0074]

In succeeding step S58, depending upon the anode off-gas supply pattern that is selected, the system controller 34 operates to allow the opening of the anode off-gas discharged valve 35 to be controlled to commence the discharging of anode off-gas, while counting a time interval elapsed from the commencement.

[0075]

Here, during the ignition period (between t1 and t2 in FIG. 6) in which discrimination is made to find out that the catalytic combustor 7 has been sufficiently activated after start of discharging anode off-gas, the temperature of the catalytic combustor 7 remains relatively low and the conversion efficiency remains inadequate, resulting in a probability where a portion of anode off-gas is discharged in unburned status. When this takes place, since unburned hydrogen remains at a concentration below the flammable lean-limit, no ignition occurs inside or outside the system, resulting in no fear of occurrence of deterioration in a safety of the system.

[0076]

In subsequent step S62, the system controller 34 calculates the flow rate of anode off-gas depending upon an elapsed time interval from commencement of discharging anode

off-gas in accordance with the selected anode off-gas supply pattern and, in step S64, the opening degree of the anode off-gas discharge valve 35 is adjusted so as to meet the calculated flow rate for thereby regulating the flow rate. In step S66, discrimination is made to find whether the elapsed time interval exceeds a given time interval (t2 in FIG. 6) and if the elapsed time interval exceeds the given time interval, then operation is routed back to step S62 to continue discharging of anode off-gas in accordance with the selected supply pattern.

[0077]

In discrimination in step S66, if the elapsed time interval is found to exceed the given time interval, operation is routed to step S68 where discrimination is made to find whether the temperature of the catalytic combustor 7 detected by the temperature detector 32 exceeds the activating temperature. If the temperature of the catalytic combustor 7 is found to be less than the activating temperature, operation is waited in step S66.

[0078]

At a timing where the temperature of the catalytic combustor 7 is found to exceed the activating temperature, since the catalytic combustor 7 has a sufficiently facilitated activity with a resultant extremely less probability in occurrence of unburned hydrogen being discharged, operation is

routed to step S70 where anode off-gas is continuously discharged at a given flow rate of anode off-gas.

[0079]

In subsequent step S72, operation is waited until the detected voltage level of the voltage detector 33 for detecting the output voltage of the fuel cell stack 3 reaches a value greater than the given voltage value. If the detected voltage level is found to exceed the given voltage value, operation is routed to step S74 wherein the anode off-gas discharge valve 35 is closed to interrupt the discharging of anode off-gas whereupon operation is restored to a given operating condition.

[0080]

According to the third embodiment set forth above, due to the presence of control through which the fuel gas is transiently and incrementally supplied during the ignition period, the fuel gas is lively combusted followed by advancement of warm-up of the catalytic combustor 7 and even when remaining at the fuel gas concentration in the vicinity of a flammable limit, the fuel gas concentration can be lowered below the flammable lean-limit. In such case, the heat value of fuel gas increases, thereby enabling the ignition time interval to be shortened.

[0081]

Also, on the contrary, depending upon a concentration

incremental pattern that is preliminarily obtained during the ignition period, an incremental flow rate of air is transiently decremented from an initial value and the hydrogen average concentration in mixed gas during the ignition period is maintained within a given range while keeping anode off-gas at a fixed flow rate. In such case, since the heat value can be increased, the activation of the catalytic combustor 7 can be relatively rapidly performed.

[BRIEF DESCRIPTION OF DRAWINGS]

FIG. 1 is a construction diagram of a fuel cell system of a first embodiment.

FIG. 2 is a timing chart for explaining a control content in the fuel cell system of the first embodiment.

FIG. 3 is a control flowchart of the first embodiment.

FIG. 4 is a timing chart explaining a control content n a fuel cell system of a second embodiment.

FIG. 5 is a control flowchart of the second embodiment.

FIG. 6 is a timing chart explaining a control content n a fuel cell system of a third embodiment.

FIG. 7 is a control flowchart of the third embodiment.

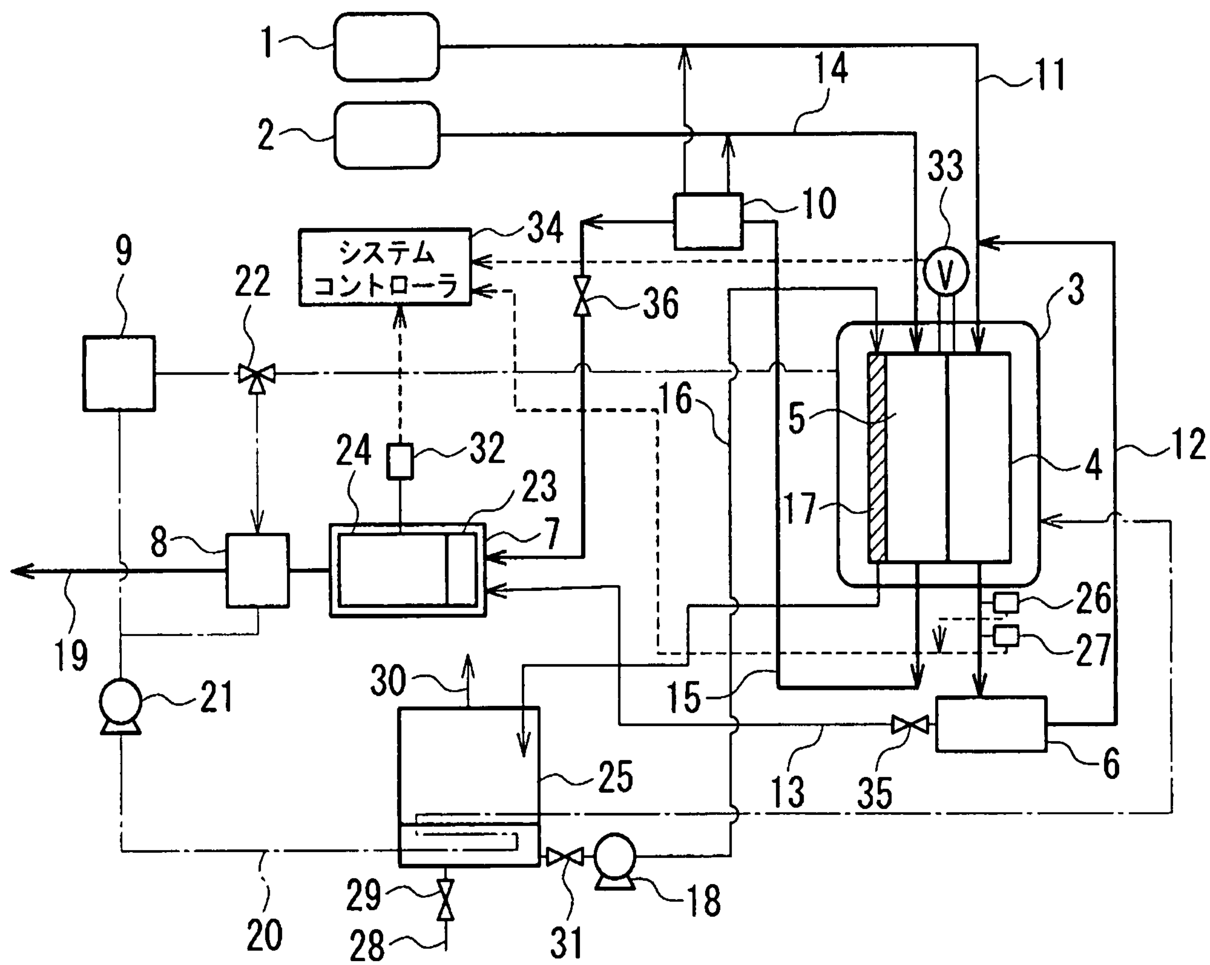
[DESCRIPTION OF THE CODES]
1: HYDROGEN SUPPLY DEVICE
2: AIR SUPPLY DEVICE
3: FUEL CELL STACK
4: ANODE
5: CATHODE
6: ANODE OFF-GAS CIRCURATION DEVICE
7: CATALYTIC COMBUSTOR
8: COOLANT HEAT EXCHANGER
9: COOLANT COOLING DEVICE

10: HUMIDIFIER
11: ANODE GAS SUPPLY PIPE
12: ANODE OFF-GAS CIRCULATION conduit
13: ANODE OFF-GAS SUPPLY conduit
14: CATHODE GAS SUPPLY CONDUIT
15: CATHODE OFF-GAS SUPPLY CONDUIT
16: WATER SUPPLY CONDUIT
17: WATER CHANNEL
18: WATER PUMP
19: EXHAUST PIPE
20: COOLANT PASSAGE
21: COOLANT PUMP
22: COOLANT PASSAGE REGULATOR VALVE
23: MIXER
24: COMBUSTION CHAMBER
25: DRAIN TANK
26: PRESSURE DETECTOR
27: TEMPERATURE DETECTOR
28: DRAIN CONDUIT
29: DRAIN VALVE
30: VENT CONDUIT
31: WATER CUT-OFF VALVE
32: TEMPERATURE DETECTOR
33: VOLTAGE DETECTOR
34: SYSTEM CONTROLLER (CONTRIL MEANS)
35: ANODE OFF-GAS DISCHARGE VALVE
36: CATHODE OFF-GAS DISCHARGE VALVE

[DOCUMENT TITLE] DRAWINGS

FIG. 1
1: HYDROGEN SUPPLY DEVICE
2: AIR SUPPLY DEVICE
3: FUEL CELL STACK
4: ANODE
5: CATHODE
6: ANODE OFF-GAS CIRCURATION DEVICE
7: CATALYTIC COMBUSTOR
26: PRESSURE DETECTOR
27: TEMPERATURE DETECTOR
32: TEMPERATURE DETECTOR
33: VOLTAGE DETECTOR
34: SYSTEM CONTROLLER (CONTRIL MEANS)

【図1】



1:水素供給装置
2:空気供給装置
3:燃料電池スタック
4:アノード
5:カソード
7:触媒燃焼器
26:圧力検出器
27:温度検出器
32:温度検出器
33:電圧検出器
34:システムコントローラ（制御手段）

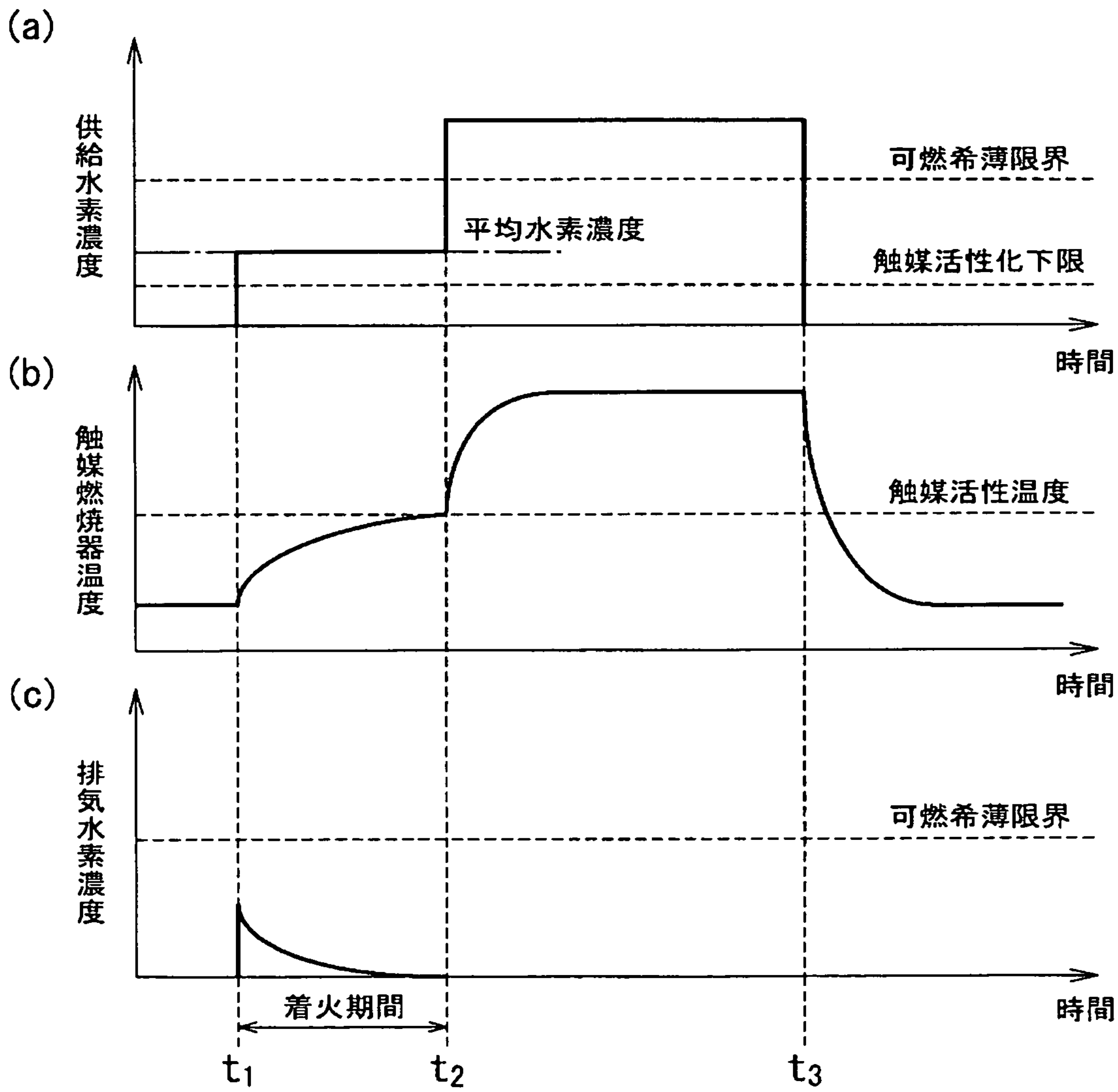
Fig. 2

(a): SUPPLY HYDROGEN CONCENTRATION
AVRAGE HYDROGEN CONCENTRATION
COMBUSTIBLE LEAN LIMIT
CATALYST ACTIVE LOWER LIMIT
TIME

(b): CATALYST COMBUSTOR TEMPERATURE
CATALYST ACTIVE TEMPERATURE
TIME

(c): DISCHARGE HYDROGEN CONCENTRATION
IGNITION PERIOD
COMBUSTIBLE LEAN LIMIT
TIME

【図２】



(a)
供給水素濃度
可燃希薄限界
平均水素濃度
触媒活性化下限
時間
(b)
触媒燃焼器温度
触媒活性温度
時間
(c)
排気水素濃度
可燃希薄限界
時間
着火期間
t_1
t_2
t_3

FIG. 3

S10: VOLTAGE DETECTION VALUE ≤ PREDETERMINED VOLTAGE
S12: TRANSMIT DISCHARGE SIGNAL
S14: ESTIMATE HYDROGEN DISCHARGE FLOW AMOUNT
S16: CALCULATE NECESSARY AIR INCREASING AMOUNT
S18: AIR INCREASE, ANODE OFF-GAS DISCHARGE
S20: CATALYTIC COMBUSTOR TEMPERATURE ≥ ACTIVE TEMPERATURE
S22: STOP AIR INCREASE
S24: VOLTAGE DETECTION VALUE ≥ PREDETERMINED VOLTAGE
S26: STOP ANODE OFF-GAS DISCHARGE

【図３】

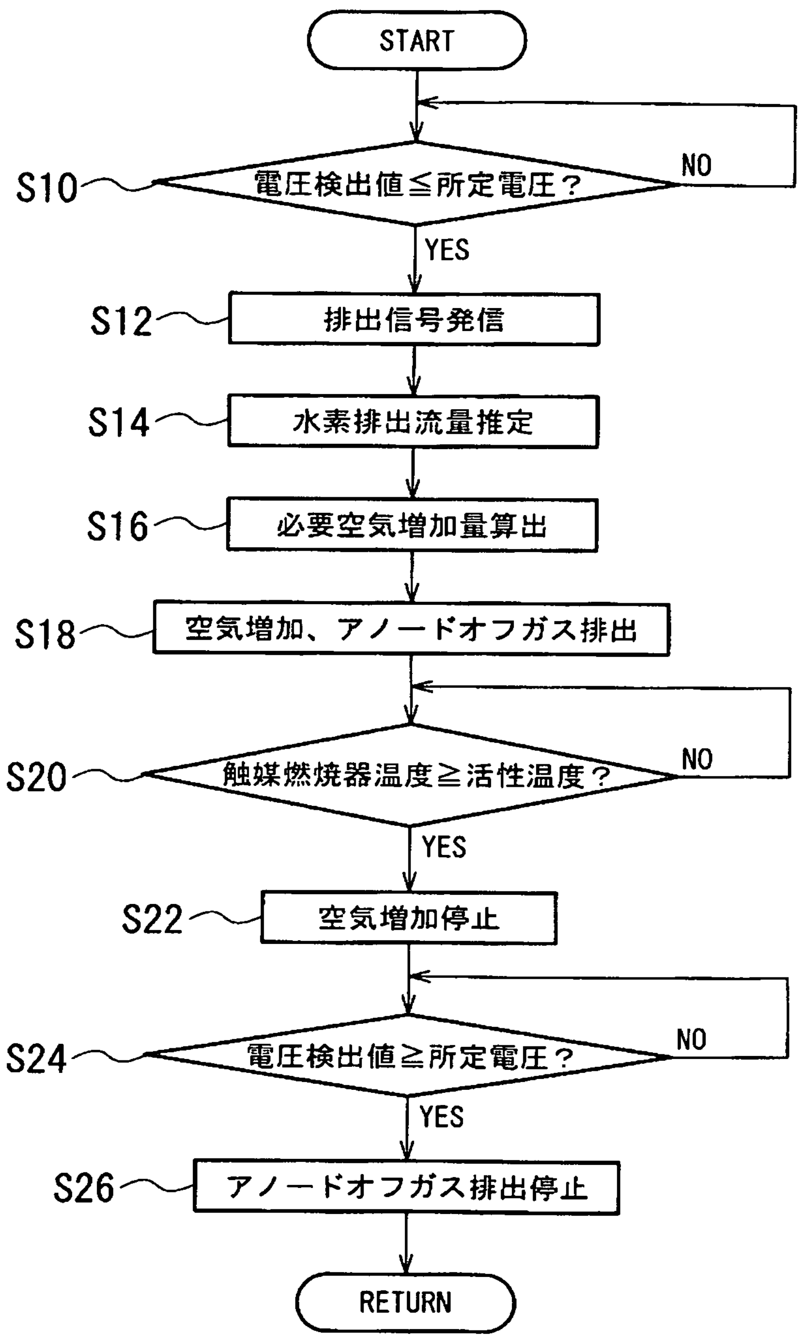

START
S10
電圧検出値≦所定電圧？
NO
YES
S12
排出信号発信
S14
水素排出流量推定
S16
必要空気増加量算出
S18
空気増加、アノードオフガス排出
S20
触媒燃焼器温度≧活性温度？
NO
YES
S22
空気増加停止
S24
電圧検出値≧所定電圧？
NO
YES
S26
アノードオフガス排出停止
RETURN

FIG. 4

(a): SUPPLY HYDROGEN CONCENTRATION
AVRAGE HYDROGEN CONCENTRATION
COMBUSTIBLE LEAN LIMIT
CATALYST ACTIVE LOWER LIMIT
TIME

(b): CATALYST COMBUSTOR TEMPERATURE
CATALYST ACTIVE TEMPERATURE
TIME

(c): DISCHARGE HYDROGEN CONCENTRATION
IGNITION PERIOD
COMBUSTIBLE LEAN LIMIT
TIME

【図４】

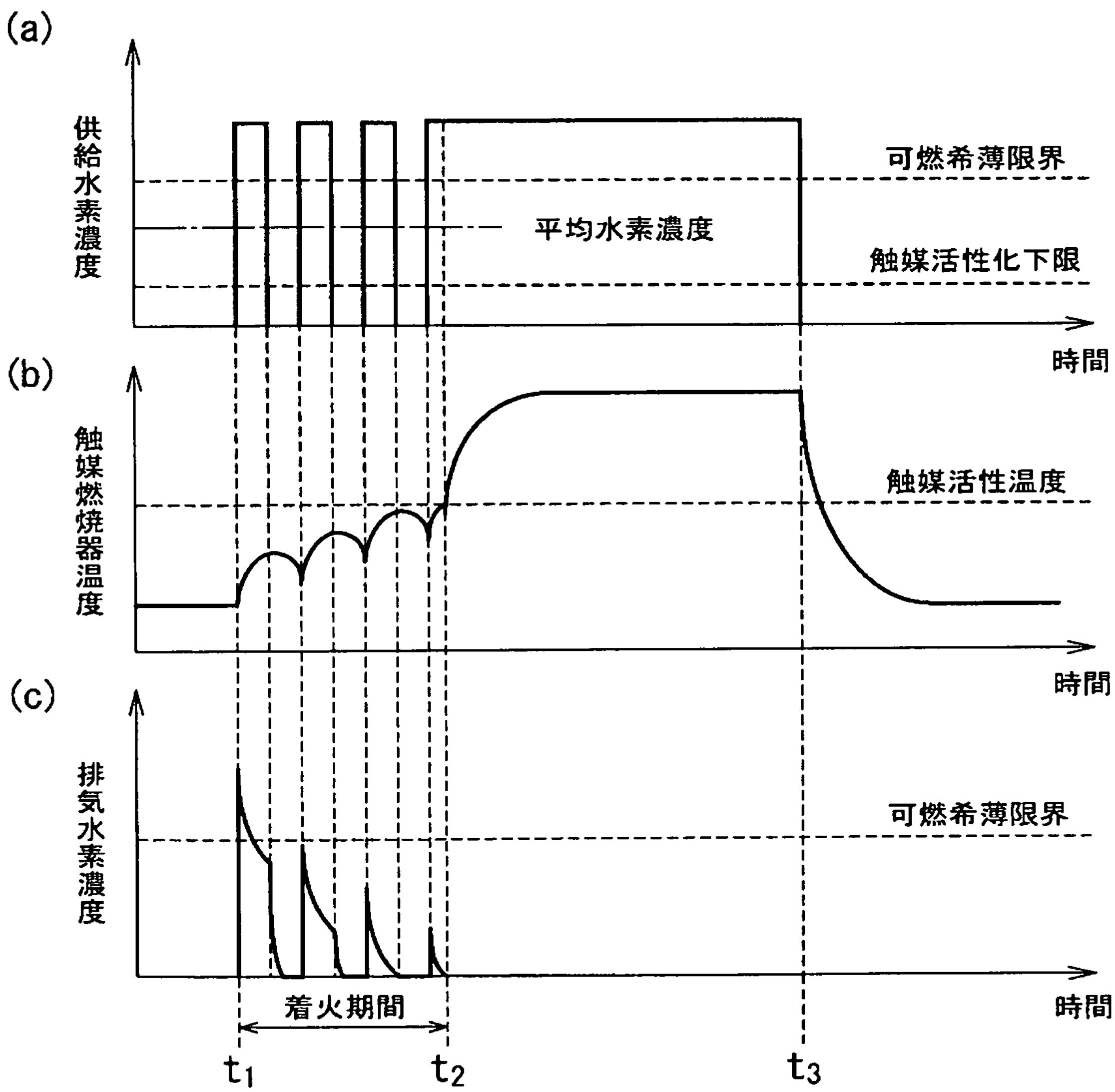

(a)
供給水素濃度
可燃希薄限界
平均水素濃度
触媒活性化下限
時間
(b)
触媒燃焼器温度
触媒活性温度
時間
(c)
排気水素濃度
可燃希薄限界
時間
着火期間
t_1
t_2
t_3

FIG. 5

S30: VOLTAGE DETECTION VALUE ≤ PREDETERMINED VOLTAGE
S32: TRANSMIT DISCHARGE SIGNAL
S34: ESTIMATE HYDROGEN DISCHARGE FLOW AMOUNT
S36: CALCULATE ANODE OFF-GAS DISCONTINUOUS DISCHARGE CONDITION
S38: ANODE OFF-GAS DISCHARGE
S40: CATALYTIC COMBUSTOR TEMPERATURE ≥ ACTIVE TEMPERATURE
S42: START ANODE OFF-GAS CONTINUOUS DISCHARGE
S44: VOLTAGE DETECTION VALUE ≥ PREDETERMINED VOLTAGE
S46: STOP ANODE OFF-GAS DISCHARGE

【図5】

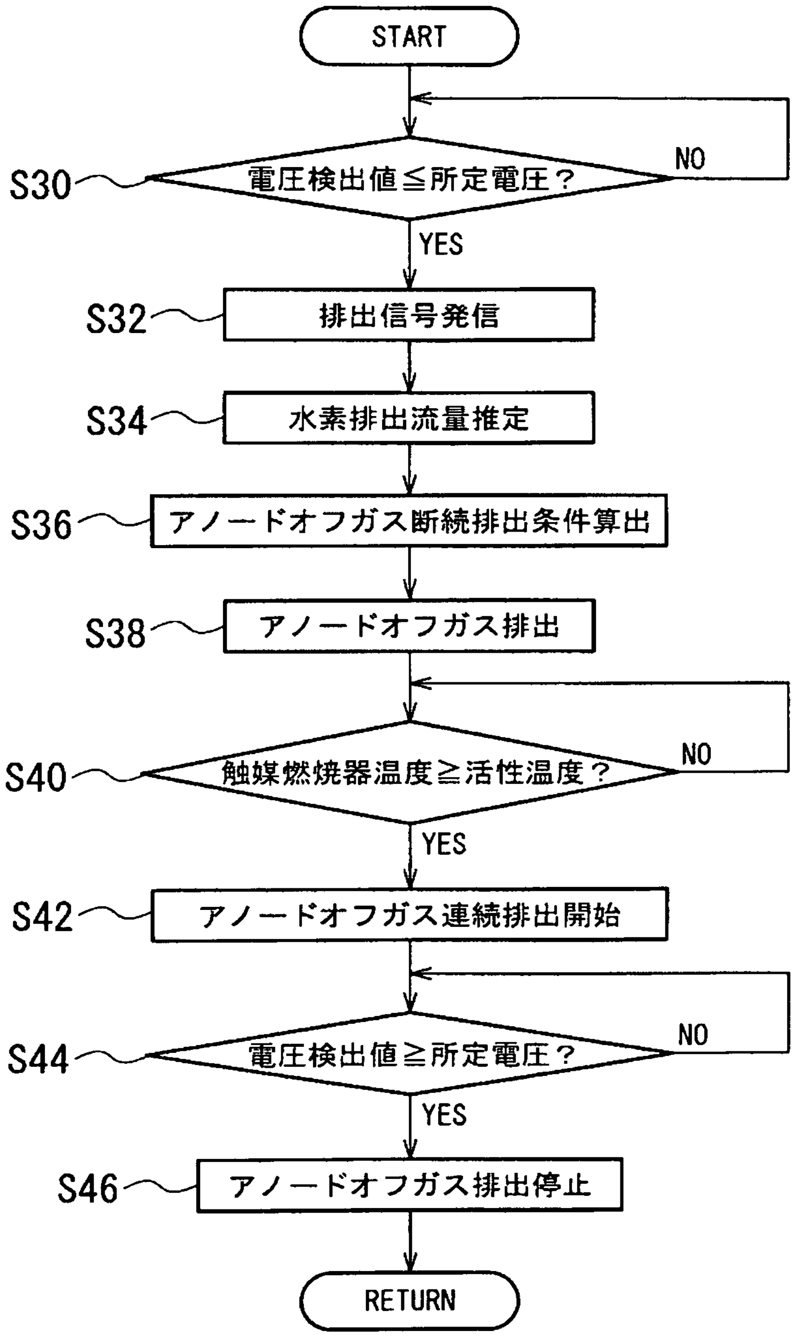

START
S30
電圧検出値≦所定電圧？
NO
YES
S32
排出信号発信
S34
水素排出流量推定
S36
アノードオフガス断続排出条件算出
S38
アノードオフガス排出
S40
触媒燃焼器温度≧活性温度？
NO
YES
S42
アノードオフガス連続排出開始
S44
電圧検出値≧所定電圧？
NO
YES
S46
アノードオフガス排出停止
RETURN

FIG. 6
(a): SUPPLY HYDROGEN CONCENTRATION
AVRAGE HYDROGEN CONCENTRATION
COMBUSTIBLE LEAN LIMIT
CATALYST ACTIVE LOWER LIMIT
TIME
(b): CATALYST COMBUSTOR TEMPERATURE
CATALYST ACTIVE TEMPERATURE
TIME
(c): DISCHARGE HYDROGEN CONCENTRATION
IGNITION PERIOD
COMBUSTIBLE LEAN LIMIT
TIME

【図6】

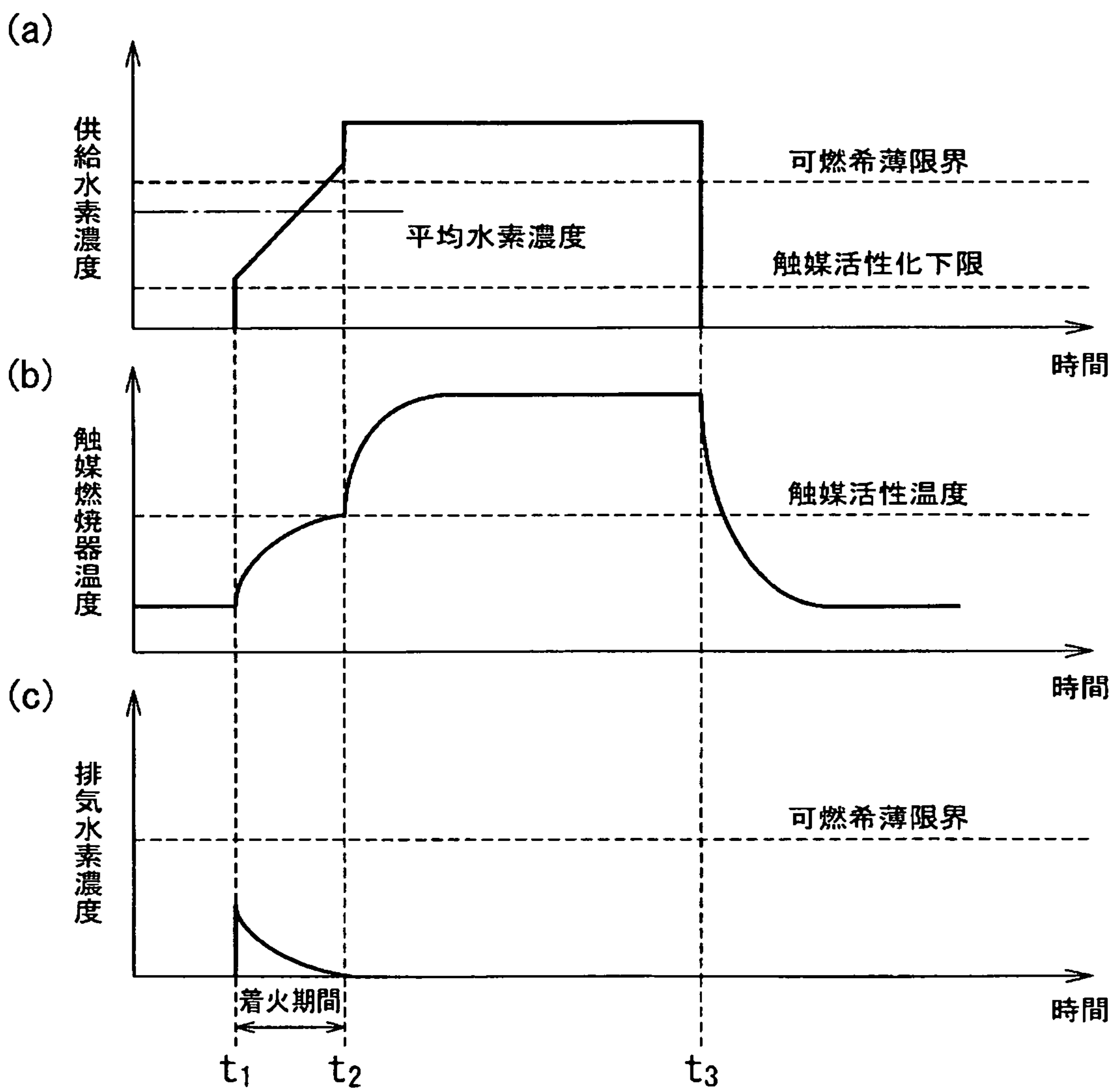
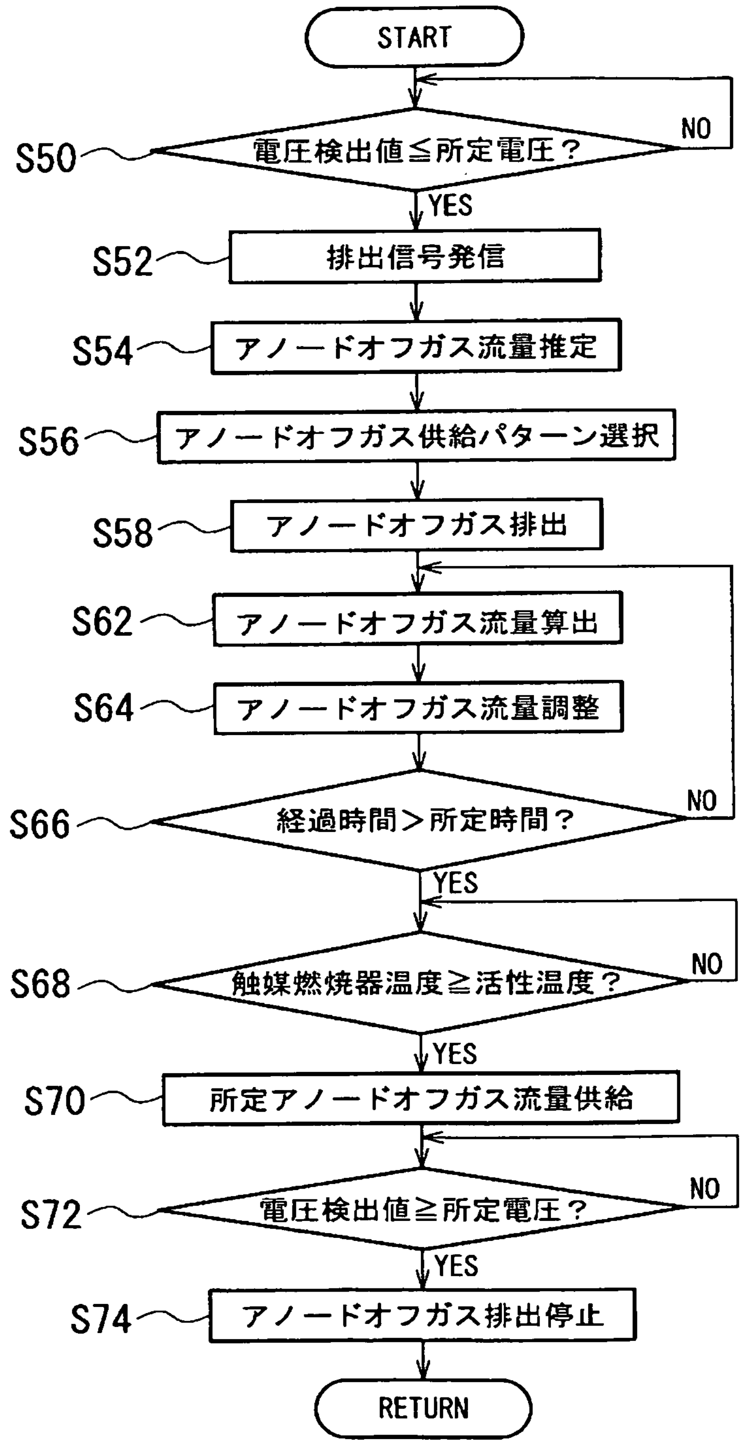

(a)
供給水素濃度
可燃希薄限界
平均水素濃度
触媒活性化下限
時間
(b)
触媒燃焼器温度
触媒活性温度
時間
(c)
排気水素濃度
可燃希薄限界
着火期間
時間
t_1
t_2
t_3

FIG. 7

S50: VOLTAGE DETECTION VALUE ≤ PREDETERMINED VOLTAGE
S52: TRANSMIT DISCHARGE SIGNAL
S54: ESTIMATE ANODE OFF-GAS FLOW AMOUNT
S56: SELECT ANODE OFF-GAS SUPPLY PATTERN
S58: ANODE OFF-GAS DISCHARGE
S62: CALCULATE ANODE OFF-GAS FLOW AMOUNT
S64: ADJUST ANODE OFF-GAS FLOW AMOUNT
S66: ELAPSE TIME > PREDETERMINED TIME ?
S68: CATALYTIC COMBUSTOR TEMPERATURE ≥ ACTIVE TEMPERATURE
S70: SUPPLY PREDETERMINED ANODE OFF-GAS FLOW AMOUNT
S72: VOLTAGE DETECTION VALUE ≥ PREDETERMINED VOLTAGE
S74: STOP ANODE OFF-GAS DISCHARGE

【図７】


START
S50
電圧検出値≦所定電圧？
NO
YES
S52
排出信号発信
S54
アノードオフガス流量推定
S56
アノードオフガス供給パターン選択
S58
アノードオフガス排出
S62
アノードオフガス流量算出
S64
アノードオフガス流量調整
S66
経過時間＞所定時間？
NO
YES
S68
触媒燃焼器温度≧活性温度？
NO
YES
S70
所定アノードオフガス流量供給
S72
電圧検出値≧所定電圧？
NO
YES
S74
アノードオフガス排出停止
RETURN

[DOCUMENT TITLE] ABSTRACT
[ABSTRACT]
[PROBLEM] to restrict a concentration of a combustible gas discharged even if a catalytic combustor is not active less than a combustible lean limit upon combusting hydrogen or an anode off-gas.
[MEANS FOR THE SOLUTION]

A catalytic combustor 7 combusts a mixed gas of a fuel gas or an anode off-gas and an oxidant gas or a cathode off-gas. A controller is provided to be operative so that during an ignition period from supply start of the mixed gas until it is determined that the catalytic combustor 7 is sufficiently active, a fuel gas concentration of the mixed gas is within a given range (more than catalyst active lower limit and less than a combustible lean limit) and after the ignition period has elapsed, the mixed gas is supplied even if the fuel gas concentration is out of the given range.

[SELECTIVE FIGURE] FIG. 1